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### AN EVALUATION OF HELICOPTER NOISE AND VIBRATION RIDE QUALITIES CRITERIA

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## AN EVALUATION OF HELICOPTER NOISE AND VIBRATION RIDE QUALITY CRITERIA

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### Abstract

This paper presents discussions of two methods of quantifying helicopter ride quality; absorbed power for vibration only and the NASA ride comfort model for both noise and vibration. Absorbed power is a measure of the rate at which the body absorbs energy when subjected to vibration. It has been used effectively as a quantitative measure of ride quality for ground vehicles, but it has not been used to quantify aircraft ride quality. The NASA ride comfort model is an empirical method for the prediction of ride discomfort due to combined noise and vibration. It is an implementation of the psychophysical laws governing human discomfort to the combined environment. This paper presents an initial evaluation of helicopter ride quality using both absorbed power and the NASA model. Noise and vibration measurements were obtained on five operational US Army helicopters. The data were converted to both absorbed power and DISC's (discomfort units used in the NASA model) for specific helicopter flight conditions. Both models indicate considerable variation in ride quality between the five helicopters and between flight conditions within each helicopter. However, the two models do not necessarily agree as to the relative levels of ride quality between helicopters. Further tests are planned to obtain subjective responses to the helicopter vibration and noise environments using the NASA ride quality simulator and to correlate these responses with the results of the two methods.

### Introduction

The specification of helicopter vibration levels in terms of acceleration has been common practice for many

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years. Acceleration is also a specification parameter in defining an acceptable vibration environment for mechanical and electronic equipment. However, if the purpose of specifying vibration levels is to guarantee a vibration environment in which the pilot and crew can function efficiently, or in which passengers are comfortable, then acceleration may not be the best measure of the vibration environment. Subjective evaluation of vehicle ride qualities can be influenced by many factors such as passenger vibration environment, the physical environment (temperature, for example), exposure duration, noise, and steady acceleration due to vehicle maneuvering. These factors combined with individual differences in subjects, introduce variabilities in subjective evaluations of vehicle ride qualities and require a statistical approach in order to obtain reliable information.

Whole-body vibration of humans is a subject around which an entire field of scientific literature has developed. Kidd, in an excellent recent paper assessing the problems associated with development of realistic helicopter vibration criteria related to ride comfort (Reference 1), points out that this body of literature has grown rapidly since the early 1930's. Kidd also discusses some of the approaches which have been taken to quantify vehicle vibration ride quality and the difficulties in relating subjective responses to measured vibration quantities such as acceleration level, vibration frequency, and exposure duration.

In an effort to determine a measurable parameter which correlates well with subjective evaluations of vehicle ride quality, the US Army Tank Automotive Command (TACOM) has conducted an extensive amount of research on whole-body vibration. They have concluded that if one measures the rate at which the body absorbs energy during vibration tests, this parameter and subjective

responses may be correlated (Reference 2). The parameter, referred to as Absorbed Power, has been used by TACOM to evaluate the ride quality of ground vehicles such as tanks, trucks, and automobiles. In general, they have found that constant subjective response correlates well with constant absorbed power. Absorbed power has also been used by others in evaluating ride quality of ground transportation systems. Wambold and Park (Reference 3) have shown correlation between absorbed power and subjective ratings of bus ride quality.

A series of experimental studies at the Langley Research Center (Reference 4) has led to the development of a general empirical model for the prediction of passenger ride discomfort in the presence of complex noise and vibration inputs. The ranges of vibration and noise stimuli used to derive the model included the amplitudes and frequencies that are known to most influence passenger comfort. The NASA ride quality model accounts for the effects of combined axis vibrations (up to three axes simultaneously) and includes corrections for the effect of vibration duration and interior noise. Output of the model consists of a single number estimate of the passenger discomfort produced by a given noise and/or vibration environment. The discomfort estimate is measured along a continuous scale that spans the range from below discomfort threshold to values of discomfort that are far above discomfort threshold.

The purpose of this paper is to present an evaluation of the noise and vibration environment on several operational US Army helicopters using the two methods mentioned. Both methods are discussed and applied to the measured ride environments. Comparisons of the results of the two methods are shown.

### Absorbed Power

#### Theoretical Development

As a result of vibration tests in a ride simulator, TACOM researchers made two observations (Reference 5): First, the more relative motion occurring between various parts of the body, the more severe the vibration; and second, doubling the amplitude of the vibration more than doubled the severity. These observations led to postulation of the theory, "The severity of a vibration is proportional to the rate at which the

body is absorbing energy." Mathematically, this may be expressed as

$$P_{avg} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T F(t) V(t) dt \quad (1)$$

where  $P_{avg}$  = average power absorbed by the subject

$F(t)$  = input force on the subject

$V(t)$  = velocity of the subject

$T$  = averaging time interval

If the velocity is written as

$$V(t) = \sum_{i=0}^{\infty} V_i \cos w_i t \quad (2)$$

and the input force as

$$F(t) = \sum_{i=0}^{\infty} F_i \sin (w_i t + \phi_i) \quad (3)$$

then the average power absorbed becomes (Reference 5)

$$P_{avg} = \sum_{i=0}^{\infty} \left[ \frac{|G(jw_i)| \sin \phi_i}{w_i} \right] A_i^2$$

$$= \sum_{i=0}^{\infty} K_i A_i^2 \quad (4)$$

where  $A_i$  = rms acceleration of the subject at frequency  $w_i$

$w_i$  = frequency of vibration

$\phi_i$  = phase angle between forces and acceleration

$G(jw_i)$  = transfer function that related force to acceleration

$G(jw) = F(jw)/A(jw)$

$j$  = imaginary number,  $j = \sqrt{-1}$

Note that the units of absorbed power are watts.

It may be noted that the transfer function  $G(jw)$  represents the equivalent mass of the subject being vibrated. This transfer function was obtained experimentally by TACOM for seated subjects by measuring the vibration responses of 21 volunteer subjects in over 1400 hours of testing. The tests resulted in the transfer functions for vertical, fore-aft, and side-to-side vibrations as well as for vibrations applied at the feet of the subjects. The experimental results for all the test subjects were averaged to obtain the mathematical transfer

functions describing the vibration response characteristics of an average young male (28 years) of approximately 150 pounds seated weight. More detailed information on the test subject characteristics as well as the mathematical expressions for the transfer functions may be found in Reference 6. With these transfer functions the power absorbed by subjects who fall in the category of the test subjects may be easily obtained once the vibration environment is known. Some examples of absorbed power calculations may be found in Reference 7.

Some important observations regarding absorbed power have become clear from the TACOM research. First, absorbed power has a physical significance and therefore can be measured or computed analytically. Secondly, absorbed power is a scalar quantity; hence, for multidegree of freedom systems, individual absorbed power values may be summed to obtain a single quantitative measure of human vibration. Finally, absorbed power can be used for periodic, aperiodic, and random vibrations.

It is important to note that vehicle type also plays a role in determining the acceptable level of vibration ride quality. In terms of absorbed power, the TACOM testing has shown that about 6 watts is the limit of acceptability for cross-country vehicles, whereas the limit for automobiles is .2-.3 watt. Absorbed power has not been previously used for aircraft, so a direct comparison with subjective responses is not currently possible. In subsequent sections, quantification of vibration on various helicopters in terms of absorbed power and DISC units will be presented. It is planned that at a later date the helicopter vibration accelerations will be used in conjunction with the NASA Langley Research Center Passenger Ride Quality Apparatus (Reference 8) to obtain subjective assessments of helicopter ride quality.

#### Applications of Absorbed Power

Gabel et al, (Reference 9), describe some research conducted by Boeing Vertol in evaluating human reaction to the helicopter vibration environment. The tests, using helicopter pilots as subjects, were conducted by vibrating a helicopter seat in which the subjects were seated and obtaining subjective reaction to the vibration. In Reference 9 the authors reviewed the work by TACOM researchers in developing the absorbed power measurement and

recommended its application in assessing helicopter ride quality, but did not apply the technique to their data.

In Fig. 1 a curve representing vertical acceleration for "acceptable comfort for 2-3 hour exposure" from the Vertol tests is reproduced from Reference 9. The data are also converted to absorbed power using the vertical transfer function of Reference 6. As may be seen from Fig. 1, beyond approximately 12 Hz the acceptable comfort curve corresponds to roughly constant absorbed power. The peak in the absorbed power curve at approximately 4.5 Hz is due to a human body natural frequency which occurs between 4 Hz and 7 Hz for various individuals. This vibration mode is thought to be caused by the mass of the internal organs above the diaphragm resonating, with the diaphragm acting as a spring (Reference 5). The increased relative motion of the organs within the body at resonance results in an increase in the amount of energy absorbed by the body.

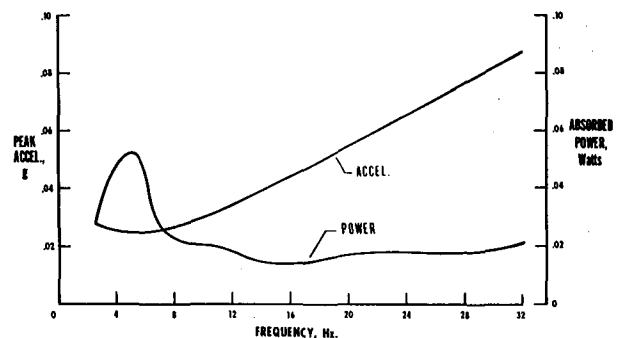


Figure 1. Conversion of Boeing Vertol subjective evaluation to absorbed power

In a second application of the absorbed power parameter, one of the curves from ISO 2631 (Reference 10) is presented in Fig. 2 in terms of acceleration and absorbed power. The curve represents the 8-hour "Fatigue - decreased proficiency boundary" for vibration in the vertical direction (along spinal direction in seated position). In this case it may be seen that the absorbed power for the "decreased proficiency boundary" is increasing only slightly beyond approximately 15 Hz. Below this frequency, two peaks in the absorbed power curve are

evident. The large peak at approximately 5 Hz corresponds to the body natural frequency discussed earlier; and the peak at roughly 12.5 Hz represents a second natural frequency that is believed to be caused by a resonating condition in the spinal column (Reference 5).

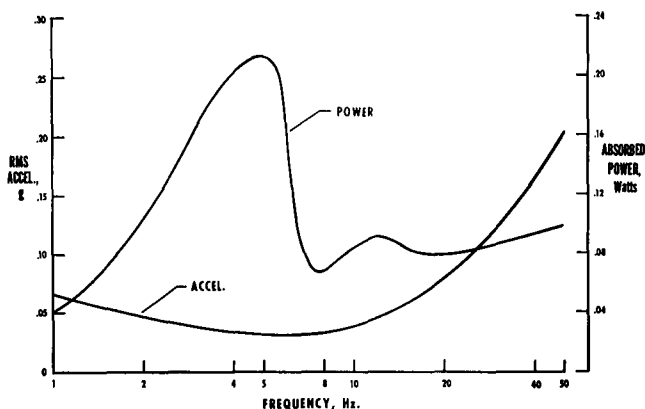


Figure 2. Conversion of ISO 2631 8-hour fatigue-decreased proficiency boundary to absorbed power

From Figs. 1 and 2 two observations may be noted. First, the frequency range in which the body tends to absorb the most energy (4-7 Hz) is the range in which the rotational speed of most currently operational helicopters will occur. The fact that the body absorbs more energy in this range might be the reason why any rotor unbalance or out-of-track condition is so readily obvious and objectionable to pilots and passengers. Secondly, in the frequency range of particular interest from a rotor-transmitted vibration point of view (approximately 12-40 Hz) there is only a slight increase in the absorbed power, indicating that a constant absorbed power criterion might be a meaningful way to specify vibration ride quality.

#### NASA Ride Comfort Model

NASA Langley Research Center has developed a comprehensive model for assessing and predicting passenger ride comfort within transportation system ride environments. The model is based upon subjective evaluations obtained from more than 2200 test subjects who were exposed to various combinations of vehicle interior noise and vibration generated by the Langley Research Center's Passenger Ride Quality Apparatus (Reference 8). These subjective evaluations were used to define the fundamental psychophysical relationships

governing human discomfort response to noise and/or vibration. It is these relationships that provide the basis for the NASA model. The basic elements, capabilities, and application of the NASA ride comfort model are described in detail in Reference 4. The important features of the model which are relevant to the present paper are summarized in the following paragraphs.

The three basic elements of the NASA ride comfort model as illustrated in Fig. 3 are: (1) empirical estimation of discomfort due to vibration in each of five axes of motion (vertical, lateral, longitudinal, roll, and pitch); (2) empirical estimation of combined axis discomfort; and (3) applications of corrections for the effects of interior noise and duration of vibration. Input to the model is the interior noise and vibration (measured at the floor) and output is a single index of discomfort measured along a scale that covers a range of values from below discomfort threshold to values far above discomfort threshold. This discomfort index relates directly to a comfort scale such as that shown in Fig. 4. Note that the discomfort scale is in discomfort units, called DISC, where a value of DISC = 1 corresponds to discomfort threshold. It should also be noted that the discomfort scale shown was derived for the general passenger public. It is reasonable to expect that the fundamental nature of the psychophysical relationships relating subjective comfort response to noise and vibration will remain essentially invariant across populations. The effect of applying the model to helicopter crewmen would likely result, at most, in a shift of the total discomfort scale, e.g., shift in discomfort threshold. The ability of the model to estimate relative ride quality, perform relative ride quality assessments, and perform ride quality trade-off analyses would not be impaired.

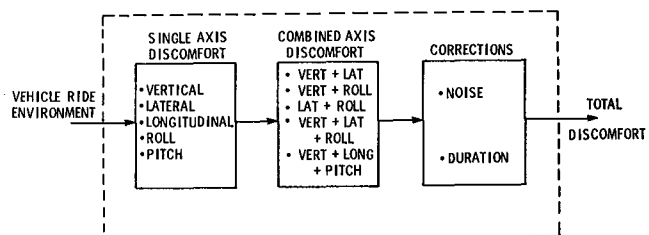


Figure 3. NASA ride comfort model concept

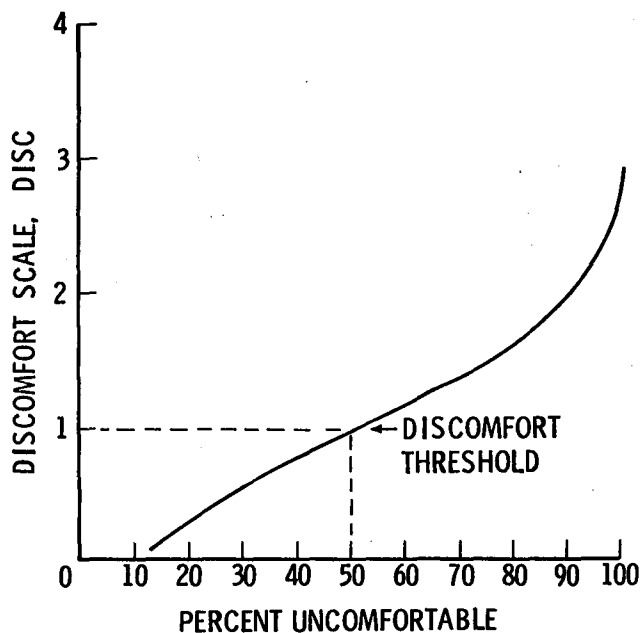


Figure 4. Discomfort, DISC, as a function of percent of passengers uncomfortable

The model has several important features that distinguish it from other models. First, the discomfort modeling is based upon the empirically derived psychophysical functions relating human discomfort response to the levels of the physical stimuli that produce the response. Thus, discomfort is modeled as a continuous function of the stimulus parameters. Secondly, the model is sensitive to changes in physical stimulus parameters such as vibration frequency, vibration acceleration level, noise octave band frequency, and noise level. Hence, it is useful for determining ride comfort design trade-offs. This same feature makes the ride comfort model especially useful as a tool for comparative assessments of vehicle ride quality. In addition, the model applies to multiple frequency and multiple axis vibrations and to either single or contiguous octave band noise spectra and corrects for the effect of vibration durations of up to 2 hours.

#### Test Helicopters and Measurement Techniques

The test aircraft used in this investigation were representatives of each helicopter type presently operational in the active US Army (Fig. 5). Included were a Bell UH-1H Iroquois, a Bell OH-58C Kiowa, a Bell AH-1S modernized TOW Cobra, a Boeing Vertol CH-47C Chinook, and a Sikorsky UH-60A Blackhawk.

Aircraft and flight crews for the test flights were provided by the Aviation Maintenance Management Training Division of the US Army Transportation School at Fort Eustis, Virginia. The aircraft were operational fleet aircraft, and no attempt was made to adjust or refine the tuning of any vibration control devices which may have been on the respective aircraft as standard equipment. The purpose of the tests was not to conduct an extensive vibration survey of each aircraft, but rather to obtain representative data to use in evaluation of helicopter ride quality as indicated by absorbed power and the NASA ride comfort model.

Two sets of instrumentation were carried on board each test flight. The first set was for vibration measurements; it consisted of a triaxial accelerometer package connected to a seven-channel FM analog tape recorder. The second set was for recording aircraft internal noise data; it consisted of a two-channel AM Analog acoustical tape recorder and two microphones. All instrumentation was provided by the Noise Effects Branch of NASA Langley Research Center.

The accelerometer package was placed as close as possible to the base of the pilot's seat and the acoustical microphones were located near the pilot's and copilot's heads. Vibration and sound recordings were then taken for a period of approximately 30 seconds at each of the following conditions: hover in-ground effect (IGE), hover out-of-ground effect (OGE), rearward flight, left and right sideward flight, 500 fpm climb at cruise velocity, and forward level flight speeds from 10 knots to maximum level flight speed for the respective aircraft.

It was originally intended that the absorbed power measurements would be made directly from the recorded vibrations using an instrument developed by TACOM for that purpose (Reference 5). However, during the data reduction process it was determined that the instrument electronics were optimized for the vibration levels and frequencies characteristic of ground vehicles; as a result, the instrument did not provide accurate absorbed power data for the helicopter vibrations. Consequently, the absorbed power measurements were obtained from the recorded vibrations using a computer program implementation of the absorbed power equations.



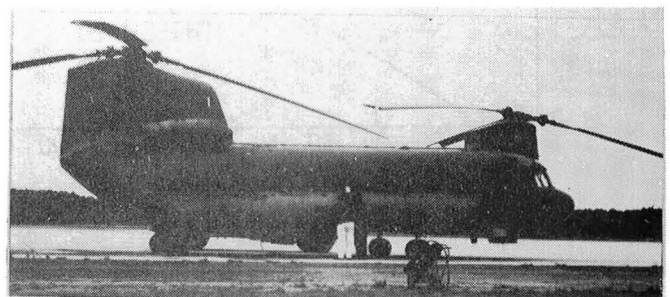
(a) UH-1H



(b) OH-58C



(c) AH-1S



(d) CH-47C



(e) UH-60A

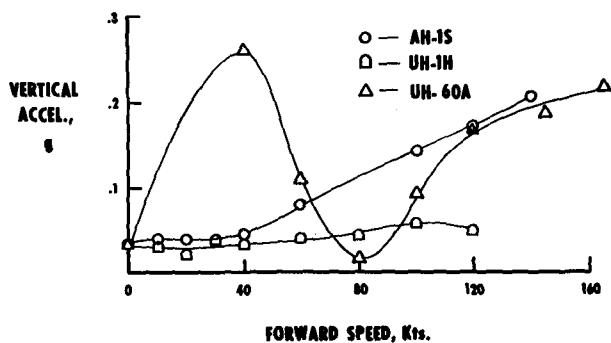
Figure 5. Helicopters used to obtain vibration and interior noise data.

### Discussion of Results

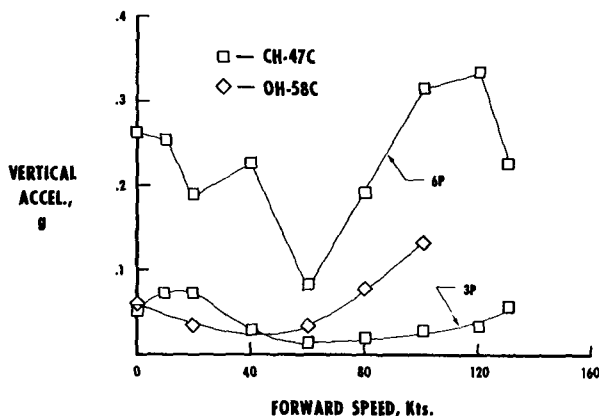
#### Data

The vertical vibration data measured in the respective aircraft as a function of forward flight speed are shown in Fig. 6(a) - (b). The hover data shown are IGE. With the exception of the CH-47C, the data shown are for the peak amplitude of the blade passage frequency harmonic of the measured acceleration

for the respective aircraft. In the case of the CH-47C, both the first blade passage frequency harmonic (3P) and the second blade passage frequency harmonic (6P) are shown because of the dominance of the higher frequency component. The significant frequencies for the various aircraft tested are shown in Table 1. The gross weights for the aircraft as tested are shown in Table 2.



(a)



(b)

Figure 6. Variation of vertical vibration with flight speed for the helicopters tested

The vibration data shown in Fig. 6 is intended to illustrate only that the general trends with airspeed were as expected and that there was considerable variation in the vibration levels between aircraft. The fact that the levels shown may be higher than expected for some aircraft or lower than expected for others should be evaluated in light of the test objectives and procedures. As was mentioned earlier the objective was to obtain vibration and interior noise data on representative aircraft at typical operating conditions. The data shown in Fig. 6 represent particular in-service aircraft, at a particular gross weight, flown on a particular day by Army operational flight crews. The data should not be interpreted as being statistically representative of the respective aircraft fleets.

Table 1. Significant frequencies for vibration considerations on helicopters tested

AIRCRAFT	1P	2P	FREQUENCY, HZ.				8P
			3P	4P	6P		
CH-47C	3.9	-	11.8	-	23.5	-	
UH-60A	4.4	-	-	17.5	-	35	
UH-1H	5.4	10.8	-	21.6	-	43	
AH-1S	5.4	10.8	-	21.6	-	43	
OH-58C	5.9	11.8	-	23.6	-	47	

Table 2. Gross weights for aircraft tested

AIRCRAFT	GROSS WEIGHT (LBS)
OH-58C	3,000
UH-1H	7,500
AH-1S	8,500
UH-60A	13,700
CH-47C	32,000

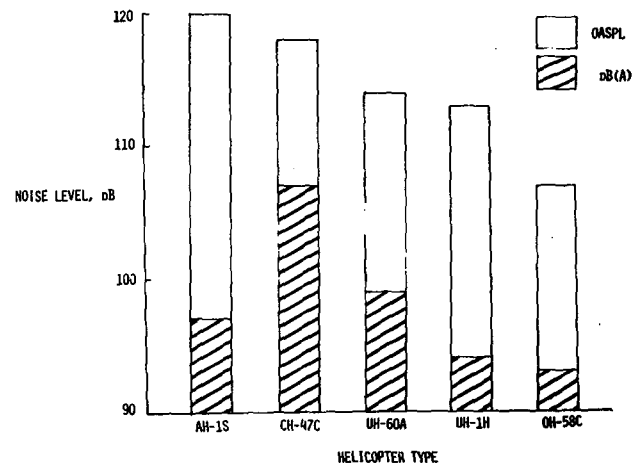


Figure 7. Interior noise data at cruise speed for the helicopters tested

Typical interior noise data measured during cruise for the various aircraft are shown in Fig. 7. The data are shown in terms of overall sound pressure level and also as modified by A-weighting. Although the noise data are shown for only the cruise flight condition, it was found that the noise levels did not change significantly over the spectrum of operating conditions flown.

#### Absorbed Power

The absorbed power results obtained from the vibration measurements on the respective aircraft are shown in Figs. 8-10 as a function of forward flight speed. The zero airspeed results shown are for hover IGE. For the test conditions other than forward flight mentioned earlier, the absorbed power values were in the same range as the forward flight values.

As was expected, the absorbed power results vary considerably between aircraft. The trends of absorbed power with forward speed for vertical vibrations show the same behavior as the more familiar vibration trends, increasing with speed beyond about 60 knots. For vertical vibration the absorbed power results indicate that the helicopter ride quality is better than the acceptable level for off-road ground vehicles (6 watts) and slightly worse than the acceptable level for automobiles (.2-.3 watt). This observation seems to agree with one's intuition regarding where the helicopter ride quality should fall in comparison with these other vehicles.

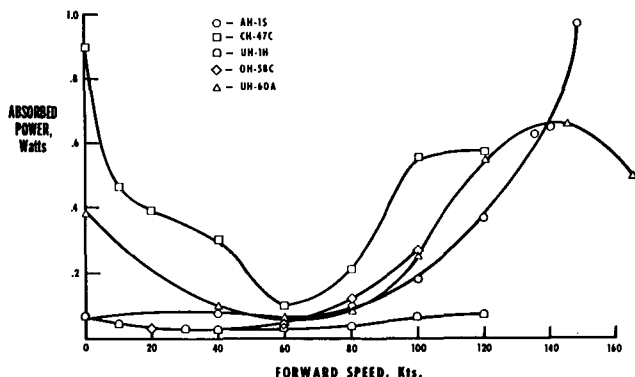


Figure 8. Absorbed power from vertical acceleration for the helicopters tested

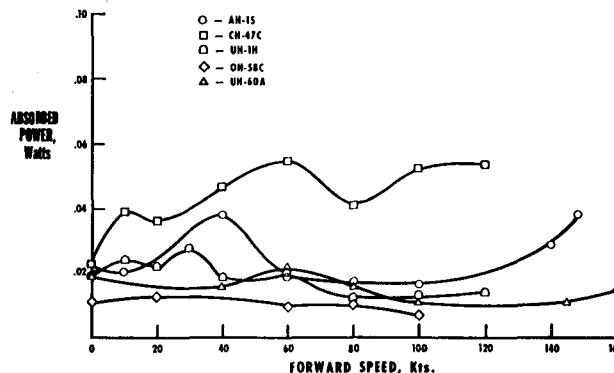


Figure 9. Absorbed power from fore-aft acceleration for the helicopters tested

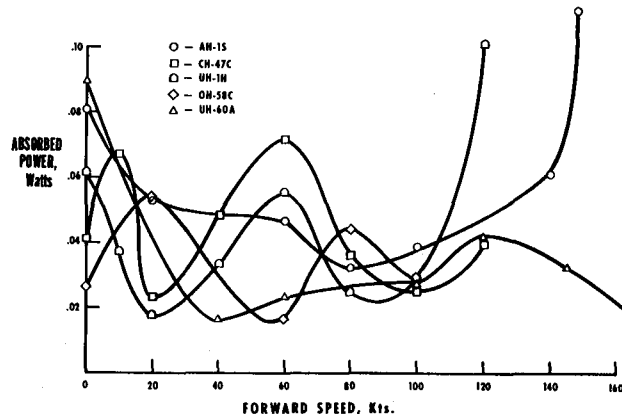


Figure 10. Absorbed power from side-to-side acceleration for the helicopters tested

As may be seen from Figs. 9 and 10, the fore-aft and side-to-side absorbed power values are roughly an order of magnitude less than the corresponding vertical values. This result stems from lower vibration levels in the fore-aft and side-to-side directions as well as the fact that the transfer functions for these directions would indicate that the body absorbs less energy in these directions at the frequencies of importance in helicopter vibrations than in the vertical direction.

An observation may be made at this point regarding the application of absorbed power for evaluation of helicopter vibration ride quality. It is well known that the significant vibrations in the helicopter airframe occur at frequencies corresponding to integer multiples of the main rotor rotational

speed. Further, the vibrations of most concern occur at the rotor rotational frequency (1P) and N times the rotational frequency (NP, or blade passage frequency) where N is the number of blades. Thus, when assessing the vibration levels in a particular helicopter, the evaluation is generally made on the basis of the highest level at these discrete frequencies. Absorbed power, on the other hand, is based on the complete frequency spectrum of the vibration. Examination of the spectrum (not shown) of absorbed power indicated that the largest contributions to absorbed power for the helicopter vibrations occurred at the integer multiples of the rotor speed. The value of absorbed power at a particular flight condition accounts for all these frequencies. It is felt that the advantage of using absorbed power as a measure of helicopter ride quality is that it does account for vibration at all frequencies in the spectrum, properly weighted to reflect the response of the body at various frequencies.

It is of interest to compare the results of Fig. 8 with Gabel's (Reference 9) curve, Fig. 1, representing "acceptable comfort for 2-3 hour exposure," and the ISO 2631 curve, Fig. 2, representing "8-hour fatigue-decreased proficiency boundary." For the most part, the absorbed power results of Fig. 8 are greater than the absorbed power for either of these "boundaries." Using the dominant frequencies of vibration for the aircraft tested, Fig. 1 would indicate that the absorbed power level should be below .02 watt and Fig. 2 would indicate that the level should be less than .09 watt. At 60 knots all the aircraft would satisfy a .09-watt requirement, but at speeds above 80 knots only one aircraft would satisfy this criterion. Below 60 knots three of the aircraft would satisfy a .09-watt requirement. None of the helicopters tested could meet an absorbed power level requirement given by Fig. 1.

#### NASA Model

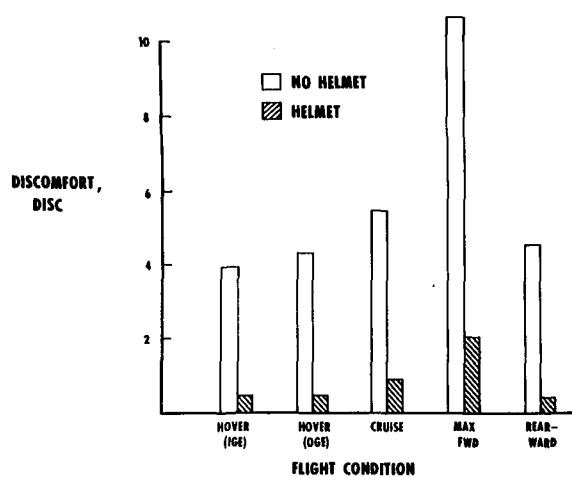
The results of applying the NASA model are shown in Figs. 11-13 for the various flight conditions measured on each of the five helicopters. In Figs. 11(a) - (e), the calculated total discomfort (due to both vibration and noise) in DISC units are shown for each helicopter and for the "helmet on" and "helmet off" conditions. These figures illustrate the effectiveness of the

helmets in reducing calculated subjective discomfort. These computations were made by incorporating the sound attenuation characteristic of the SPH-4 helmets (Reference 11) into the comfort model. It is interesting to note that high DISC estimates ( $>4$ ) were obtained for all flight conditions for all five helicopters. These estimates were greatly reduced when helmet attenuations were added and, in a few cases, DISC values less than one occurred. When it is remembered that DISC = 1 corresponds to a ride environment that 50 percent of the passenger public would rate as being uncomfortable, it is apparent that most of the measured environments would still be rated unacceptable. This is due in part to the fact that although the noise levels were reduced by using helmets, the vibration environment remained.

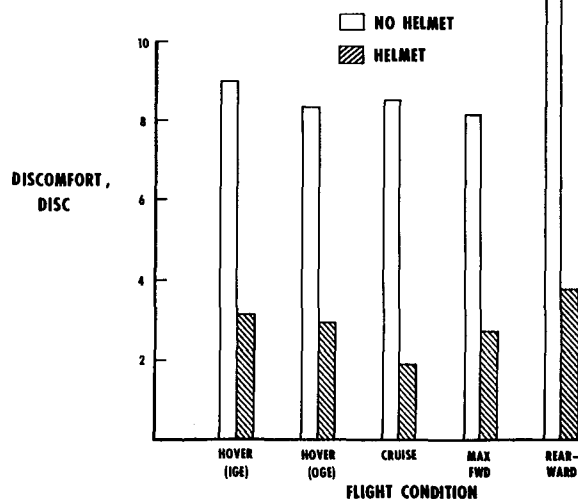
The NASA model was applied to compute the relative discomfort contributed by the noise and vibration components of the environments and the results for the cruise condition are shown in Fig. 12. Note that the NASA model indicates that in three of the helicopters (AH-1S, CH-47C, UH-60A) the vibration is the dominant contributor to subjective acceptance and in two helicopters (UH-1H, OH-58C) the noise is slightly dominant. Total discomfort is obtained by simply summing the two individual contributions. The corresponding percentage of passengers (wearing helmets) who would rate the noise and vibration during cruise as uncomfortable are shown in Fig. 13.

#### Comparison of Absorbed Power Results with NASA Ride Comfort Model Estimates

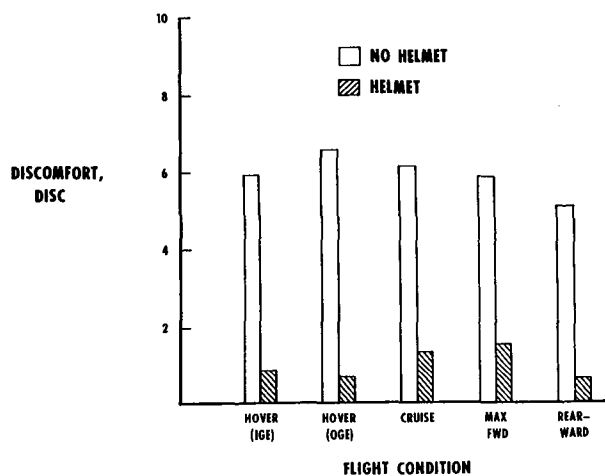
Comparisons of results of the NASA model with those of absorbed power are shown in Figs. 14(a) - (c). The three conditions shown are hover (IGE), cruise, and maximum cruise for five Army helicopters. The DISC scale was previously defined. The absorbed power scale indicates the amount of power in watts represented by the measured vibration in three linear axes. No absorbed power level has been determined as a criterion for comfort, acceptability, or performance. Thus the absorbed power scale is not necessarily in concert with the DISC scale and comparisons may be made only on a relative magnitude basis. It should also be noted that the DISC estimates are for vibration only for these comparisons since absorbed power values are based only on vibration. In general, the overall trends appear to agree, that is,



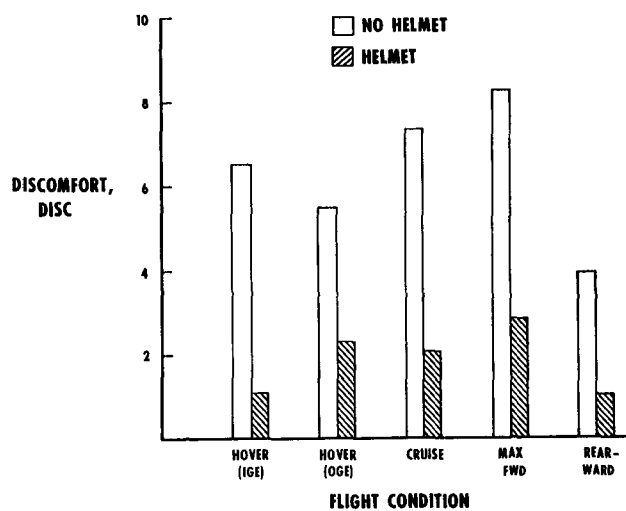
(a) UH-1H



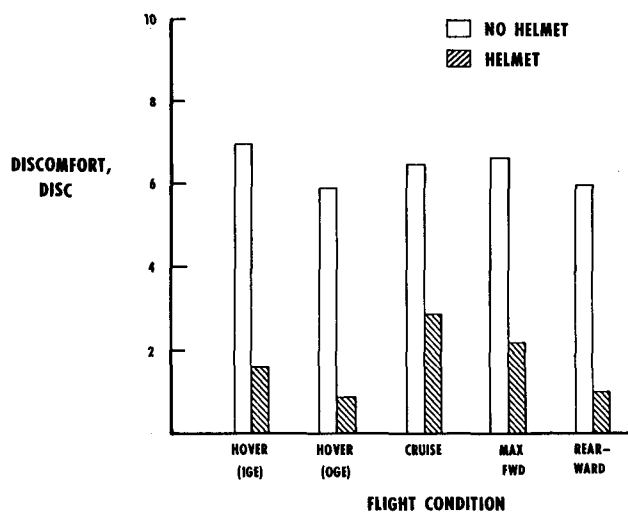
(d) CH-47C



(b) OH-58C



(e) UH-60A



(c) AH-1S

Figure 11. Calculated discomfort values for the respective helicopters at various flight conditions using the NASA model

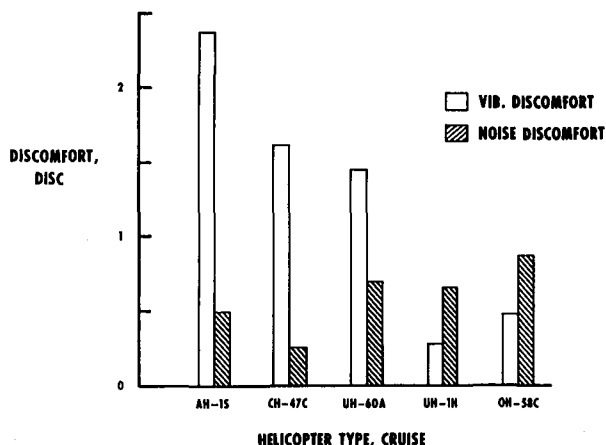


Figure 12. Relative contribution of noise (with SPH-4, helmet) and vibration to discomfort as computed by the NASA model

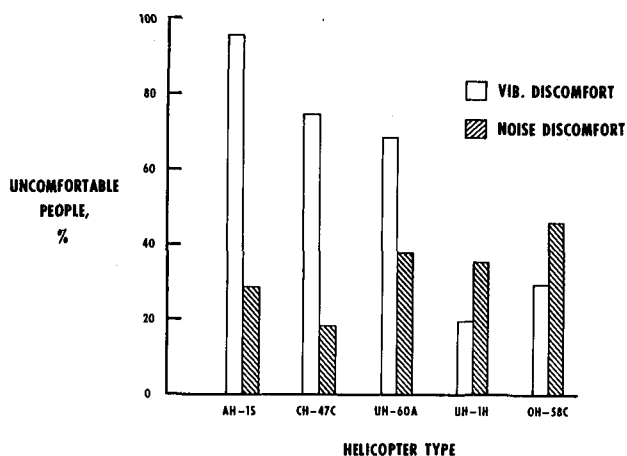
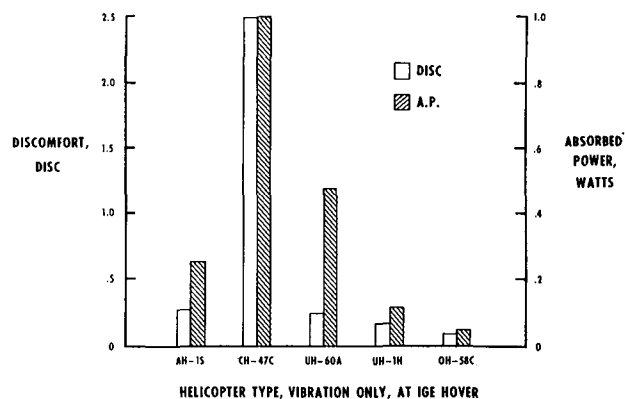
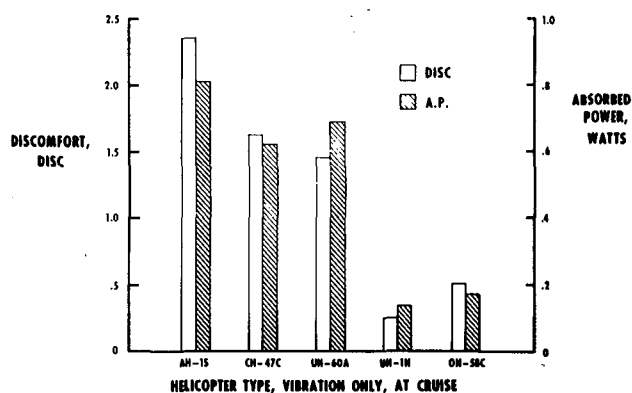


Figure 13. Percentage of passengers (as indicated by the NASA model) who would rate the cruise condition uncomfortable

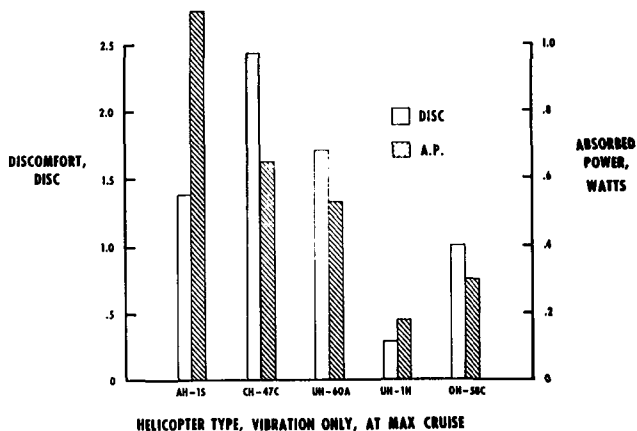
where the discomfort estimates are high, the absorbed power is also high (the values for the UH-60A at hover IGE and the AH-1S at max. cruise are exceptions). However, the two models do not necessarily agree as to the relative levels of ride quality between helicopters. Although the placement of the DISC scale and the absorbed power scale is somewhat arbitrary on the figures, it is apparent that the relative values of DISC's are sometimes higher and sometimes lower than the absorbed power ratings.



(a) IGE Hover



(b) Cruise



(c) Max. Cruise

Figure 14. Comparison of NASA model discomfort calculations with absorbed power

Since, as previously mentioned, it is likely that helicopter crew persons would establish a different acceptance threshold than the general passenger public, it is planned to derive a scale similar to Fig. 4 in a series of future tests on the NASA Passenger Ride Quality Apparatus using helicopter pilots as subjects. The objectives of these tests will be (1) to obtain pilot's ratings of acceptability/annoyance, (2) to obtain their threshold of discomfort, (3) to provide data to assist in validating both the comfort model and the absorbed power concept, and (4) to determine the value of absorbed power that corresponds to an acceptability threshold.

#### Concluding Remarks

This paper has presented discussions of two methods of quantifying helicopter ride quality; absorbed power for vibration only and the NASA ride comfort model for both noise and vibration; and has presented an initial evaluation of helicopter ride quality using both methods. Noise and vibration measurements were obtained on five operational US Army helicopters and the data were converted to both absorbed power and DISC's for specific helicopter flight conditions. Both models indicated considerable variation in ride quality between the five helicopters and between flight conditions within each helicopter. However, the two models did not necessarily agree as to relative levels of ride quality between helicopters. Further tests are planned to obtain subjective responses to the helicopter noise and vibration environments using the NASA ride quality simulator and to correlate these responses with the results of the two methods.

#### References

1. Kidd, D. L., "Assessment of Helicopter Vibration Criteria," American Helicopter Society Preprint No. 81-22, 37th Annual Forum of the American Helicopter Society, New Orleans, LA, May 1981.
2. Pradko, F., Lee, R. A., and Greene, J. D., "Human Vibration Response Theory," American Society of Mechanical Engineers, Paper 75-WA/HUF-19, Winter Annual Meeting, Chicago, IL, November 7-11, 1965.
3. Wambold, J. C., and Park, W. H., "Objective Ride Quality Evaluation." The Pennsylvania Transportation Institute Report PTI 7412, The Pennsylvania State University, March 1974.
4. Leatherwood, J. D., Dempsey, T. K., and Clevenson, S. A., "A Design Tool for Estimating Passenger Ride Comfort Within Complex Ride Environments," Human Factors, 1980, 22(3), 291-312.
5. Lee, R. A., and Cumbow, J., "Absorbed Power Ride Measurement Instrument," US Army Tank-Automotive Research and Development Command Technical Report 12415, December 1978.
6. Lins, W. F., "Human Vibration Response Measurement," US Army Tank Automotive Command Technical Report No. 11511, June 1972.
7. Lee, R. A., and Pradko, F., "Analytical Analysis of Human Vibration." Society of Automotive Engineers, Paper 680091, Automotive Engineering Congress, Detroit, MI, January 8-12, 1968.
8. Clevenson, S. A., and Leatherwood, J. D., "On the Development of Passenger Ride Acceptance Criteria," Shock and Vibration Bulletin, Bulletin 43, Pt. 3, US Department of Defense, June 1973.
9. Gabel, R., Henderson, B. O., and Reed, D. A., "Pilot and Passenger Vibration Environment Sensitivity," Journal of the American Helicopter Society, Vol. 16, Nov 3, July 1971.
10. Anon., "Guide for the Evaluation of Human Exposure to Whole-Body Vibration," International Standard ISO 2631, 1978.
11. Megehee, J. H., "Service Tests of SPH-4 Protective Helmet (U)," Army Aviation Test Board, Ft Rucker, AL, September 1969, AD 8623574.

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16. Abstract This paper presents discussions of two methods of quantifying helicopter ride quality; absorbed power for vibration only and the NASA ride comfort model for both noise and vibration. Absorbed power is a measure of the rate at which the body absorbs energy when subjected to vibration. It has been used effectively as a quantitative measure of ride quality for ground vehicles, but it has not been used to quantify aircraft ride quality. The NASA ride comfort model is an empirical method for the prediction of ride discomfort due to combined noise and vibration. It is an implementation of the psychophysical laws governing human discomfort to the combined environment. This paper presents an initial evaluation of helicopter ride quality using both absorbed power and the NASA model. Noise and vibration measurements were obtained on five operational U.S. Army helicopters. The data were converted to both absorbed power and DISC's (discomfort units used in the NASA model) for specific helicopter flight conditions. Both models indicate considerable variation in ride quality between the five helicopters and between flight conditions within each helicopter. However, the two models do not necessarily agree as to the relative levels of ride quality between helicopters. Further tests are planned to obtain subjective responses to the helicopter vibration and noise environments using the NASA ride quality simulator and to correlate these responses with the results of the two methods.					
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